



# EXPLORE FLIGHT

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## **NASA Electrified Propulsion Research Summary**

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# Potential Benefits of Electrified Aircraft Propulsion



## Improvements to highly optimized aircraft like single-aisle transports

- Enables significant fuel burn reduction from alternative architectures and operational schemes in addition to other benefits from improved engine cores or airframe efficiencies



## Help open Urban Air Mobility market

- Enable new VTOL configurations with the potential to transform transportation and services.



## Revitalizing the economic case for small short-range aircraft services

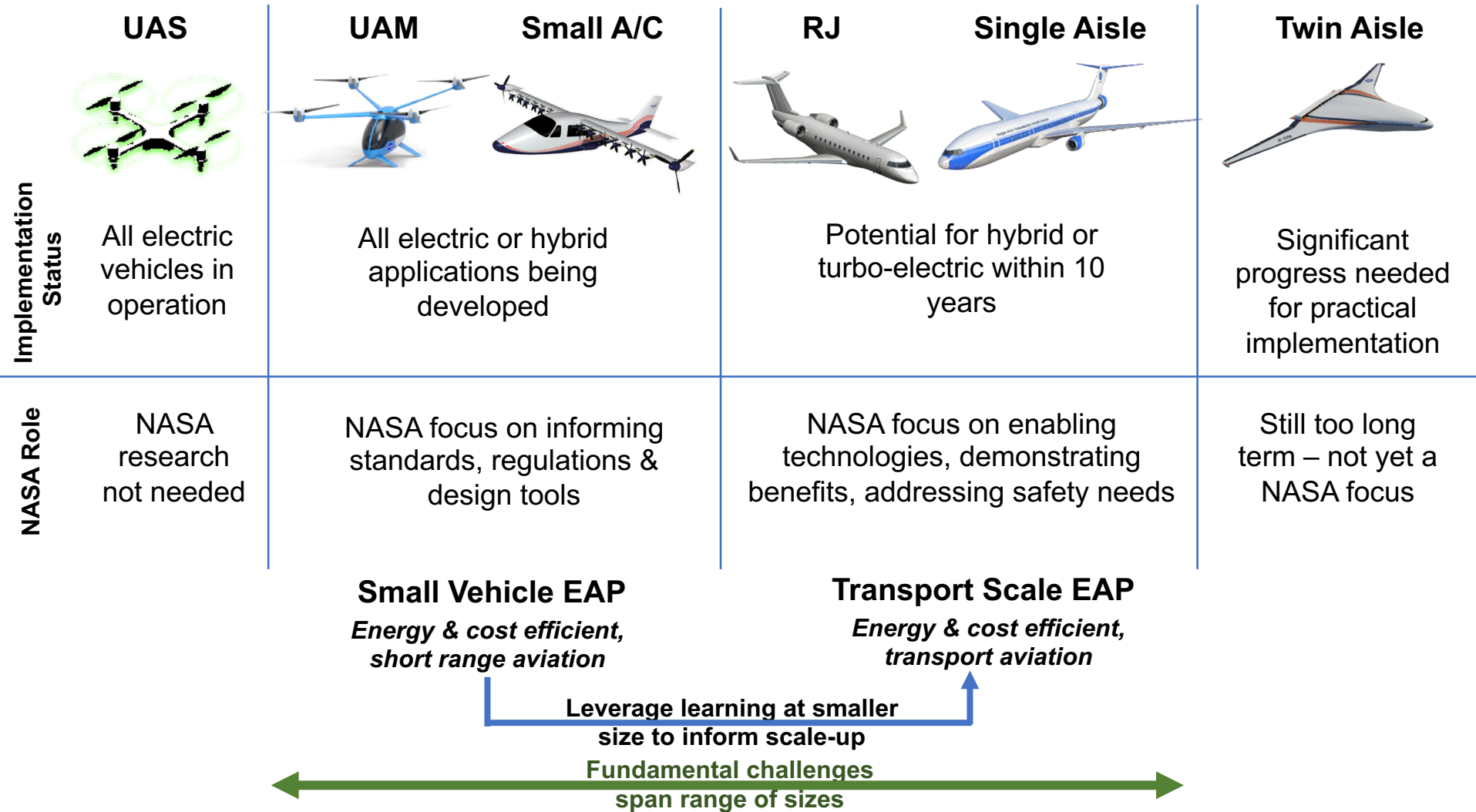
- The combination of electrified propulsion aircraft with higher levels of autonomous operations could reduce the operating costs of small aircraft operating out of community airports resulting in economically viable regional connectivity.



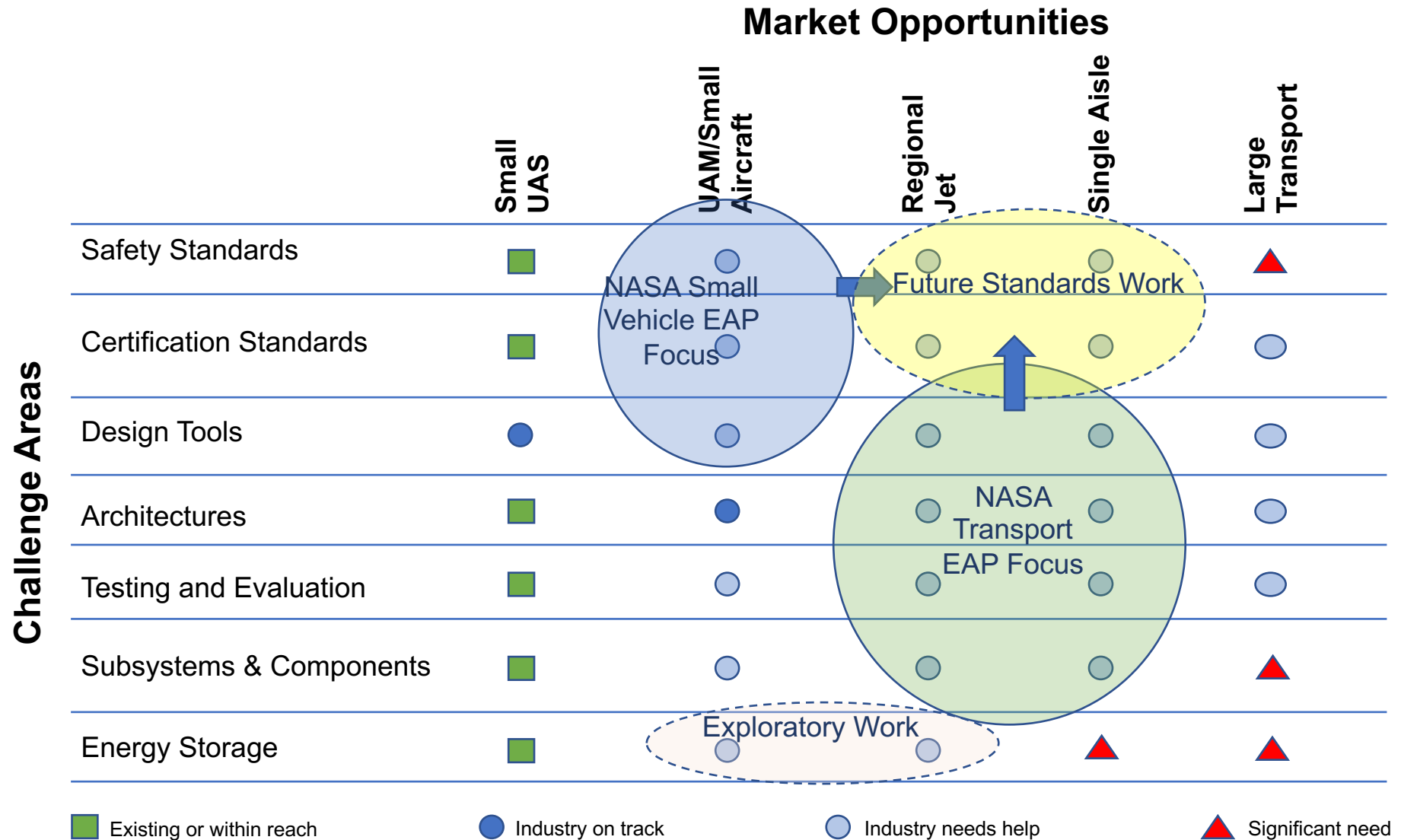


# Electrified Aircraft Propulsion – a 60,000 ft Perspective

(a range of vehicles and range of needs)



# EAP Challenges Across Multiple Vehicle Classes





# Multiple Aspects to Electrified Aviation Propulsion



## EAP encompasses more than just electrical components:

### Electrical generation, storage and distribution

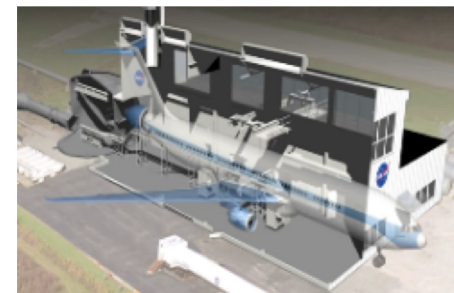
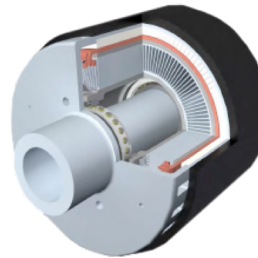
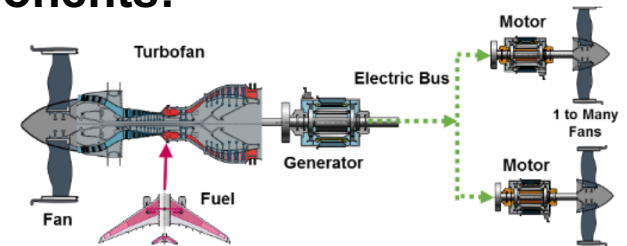
- Electrical power components (e.g. inverters, motors, generators & systems)
- Power storage
- Power extraction
- System architectures

### Coupled turbine systems

- Small core turbomachinery
- New material systems

### System benefits

- Novel propulsion airframe integration
- Systems analysis tools
- Test capabilities



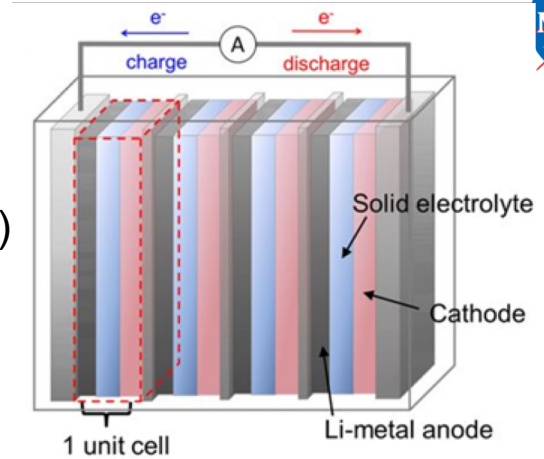
Electrified Aircraft Propulsion (EAP) – the suite of technologies and capabilities that will enable air vehicles to leverage benefits of electricity in their propulsion systems.

# EAP Research Approach



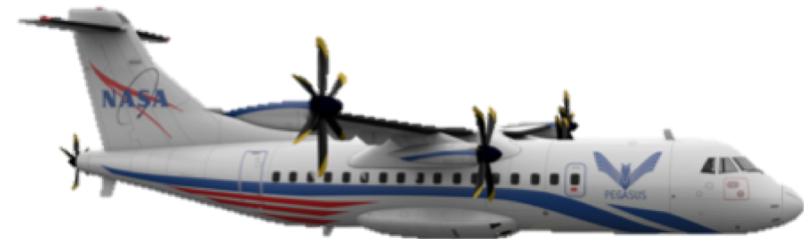
## Computational/Laboratory

- Develop tools for better design trades
- Investigate new materials (e.g. insulators)
- System studies
- Component development



## Ground Test

- Develop ground test capabilities (e.g. NEAT)
- Altitude simulation
- Component development & testing
- Reliability and thermal management



## Flight Test

- Validation of system performance
- Better understand altitude & environmental effects

Utilize the approach that is best suited to achieve results

# Transport-Class Advancing Technical and Integration Readiness



**0** Early conceptualization & identification of KPP's/ technology gaps; component advancement; ground test capability gap assessment

The block contains three images: a side view of a transport aircraft, a close-up of a motor component, and a schematic diagram of a power distribution system with multiple 250 kW outputs.

**2009-2015**  
**TRL 1-2**

NASA in-house & NASA-sponsored university/industry efforts advancing MW motors & inverters for EAP

**1** Ground testing of Key electrical components (work is ongoing but must accelerate)

The image shows a laboratory environment with various electrical testing equipment, including a large power supply unit and a circuit board being tested.

**2016-2018+**  
**TRL ~3**

NASA in-house & industry efforts raise the TRL level of motors and inverters

**2** Integrate in a flight system (likely existing airframe) – leveraging experience from X-57

The diagram illustrates the integration of an electric bus system into an aircraft airframe. It shows a cross-section of the aircraft with a central electric bus connected to various components: a Turbopan, a Fan, a Fuel system, a Generator, and a Motor. The bus is labeled 'Electric Bus' and '1 to Many Fans'. Below the diagram is a 3D rendering of the aircraft with yellow dashed lines indicating the power distribution paths.

**2018-2020**  
**TRL ~4**

NASA in-house & industry efforts leading to ground demo of TRL 4 level end-to-end power system

**3** Flight Experiments in relevant environment

The image shows a transport aircraft in flight, with a NASA logo on the tail. Below the image is a yellow box containing a list of key data informing product decisions.

- Key data informing product decisions
- Knowledge to support certification
- Learning to inform further fundamental research

**2021-2023**  
**TRL 5-6**

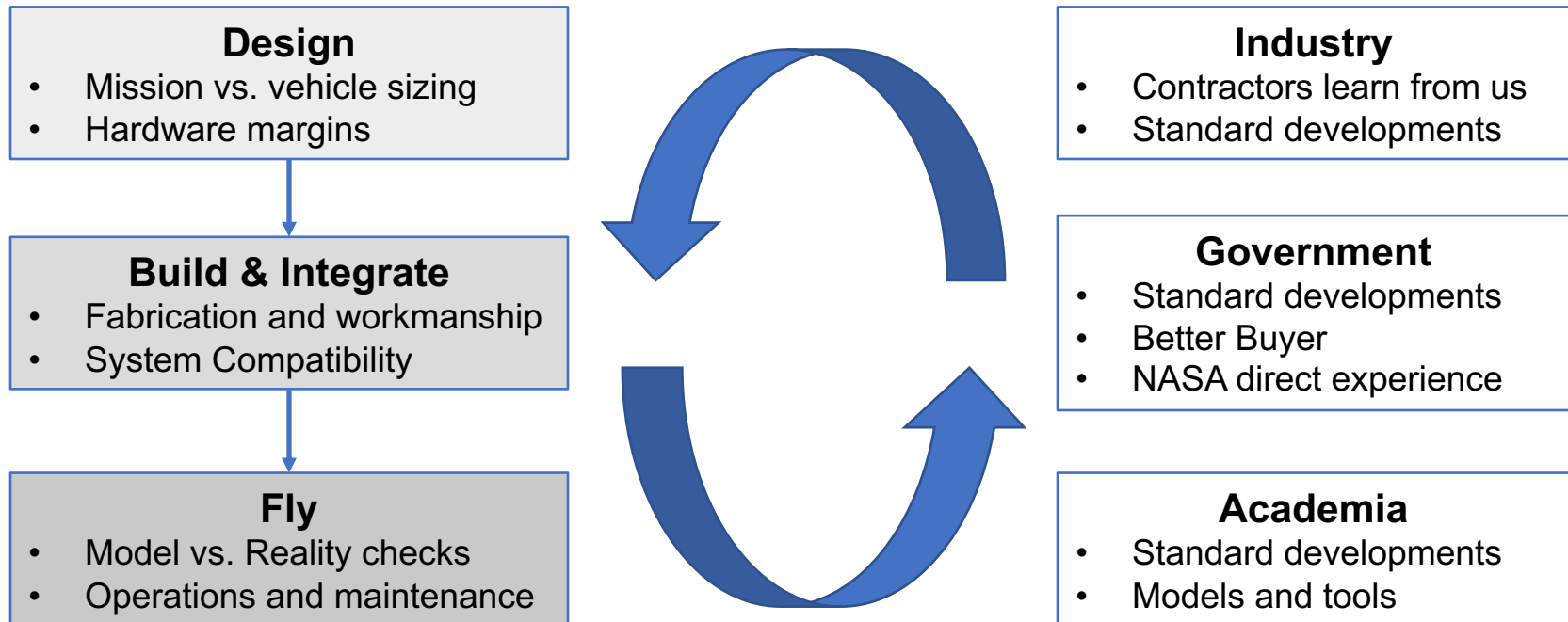
Flight demo of end-to-end MW EAP power system with application to transport aircraft.



# Small Vehicle (Fixed Wing) EAP

Build – Learn – Fly – Share

Why is flight important? What can't we learn on the ground?



X-57 will be successful if Nation's ability to design, test, and certify electric aircraft has advanced – evidenced through successful knowledge transfer to industry, government, and academia; product commercialization; and TRL advancement



# Small Vehicle (eVTOL) EAP



Target unique challenges of eVTOL propulsion systems:

- low power, high-density motors
- high duty cycle
- high C-rate (current draw) in high power conditions (hover)
- multi-rotor vehicle = multi-string propulsion systems; wide range of possible architectures
- small operating volume = thermal management issues

Use NASA eVTOL concept vehicles to focus work & conduct trade studies



**Lift + Cruise: Turboelectric**



**Tiltwing: Turboelectric**



**Side-by-side: Parallel Hybrid-Electric**



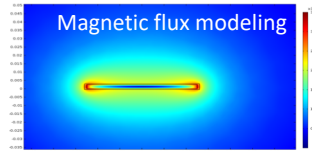
**Quadrotor: Electric**

# Enabling Fundamental Technologies for EAP



## High Voltage Power Cabling

**Goal** - large reduction of weight & concurrent increase in power for high voltage power distribution.  
**Why do more?**- SOA high voltage cabling is large & heavy. Planes are limited to 250V. Industry is actively pursuing 500 V operation. 1-2 MW needed for urban air mobility; 30 MW is required for regional jet service. Thermal management issues.



## Advanced Multi-Functional Materials & Manufacturing

**Goals** - Light weight components & actuation

- Stream line processing & manufacturing
- Efficient interface design
- Near net shape actuator design by additive manufacturing

**Why do more?**- replace heavy components and hydraulics.

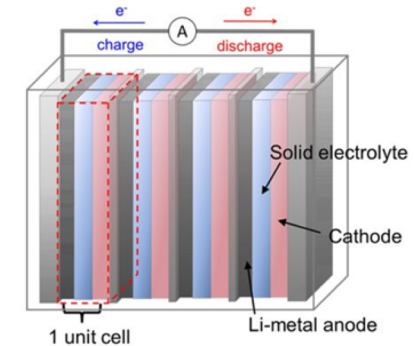
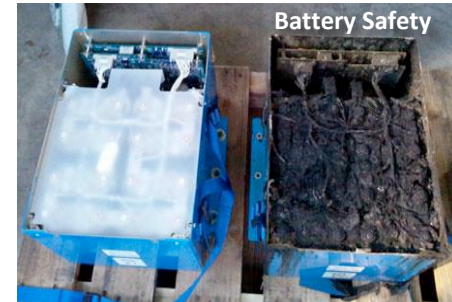


## New Energy Storage

**Goals**

- Solid state architectures
- Safer
- New chemistries
- Higher energy densities
- Lighter weight

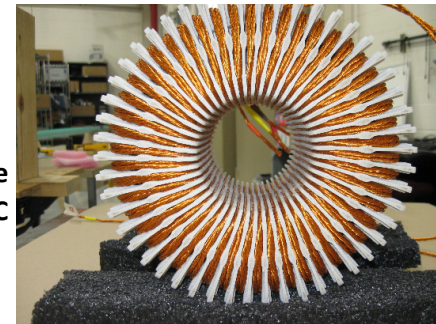
**Why do more?**- aero has unique requirements – higher cycle life, lighter weight, safety.



## Soft Magnetic Materials

**Goal** - improved efficiency

Soft magnetics are in all electric motors, inductors & components, actuators, EMI shielding, electronics, sensors, etc. **Why do more?**- otherwise component size, weight & temperature increase with higher voltages.



Inductor made with NASA GRC Ribbon for Eaton.



Coil of Soft Magnetic Ribbon



# Summary



- More electric systems will impact aviation ranging from small all-electric vehicles to larger aircraft with hybrid or turbo-electric propulsion.
- US industry collaboration interest is high and international competition fierce with increasing R&D budgets in pursuit of more electrified vehicles
- NASA has developed strategy that provides leadership and a vision for this more electric future and addresses key areas where industry needs assistance.



Thank you